[Document Type] Specification

[Title of the Invention] FUEL CELL POWER SUPPLY UNIT

[Claims]

[Claim 1]

A fuel cell power supply unit comprising a fuel cell and an electric double layer capacitor that are placed in parallel and are used in a good electrical conducting state characterized in that the fuel cell power supply unit sets, based on a predetermined variation of load current width, characteristic values of said fuel cell and a reacting gas supply system of the fuel cell, and a characteristic value of said electric double layer capacitor, an excess supply amount with respect to an amount of the reacting gas in an output equilibrium state where the reacting gas supplied by said reacting gas supply system of the fuel cell supplies to said fuel cell is equilibrated.

[Claim 2]

The fuel cell power supply unit according to claim 1 characterized in that the characteristic value of said fuel cell is a fuel cell electromotive force and an internal resistance derived from a current-voltage characteristic of said fuel cell, the characteristic value of said electric double layer capacitor is an internal resistance and a capacitance of said electric double layer capacitor, and the characteristic value of said reacting gas supply system of the fuel cell is a responsiveness to an change in a output command value to said fuel cell.

[Claim 3]

The fuel cell power supply unit according to claim 1 or claim 2 characterized in that the excess supply amount supplied to said fuel cell with respect to the amount of the reacting gas in the output equilibrium state and the characteristic value of said electric double layer capacitor are set such that a synthetic output voltage of said fuel cell and said electric double layer capacitor immediately after the predetermined load current variation is given is higher than a voltage corresponding to the output current of said fuel cell that is equilibrated with the amount of the reacting gas in which said reacting gas supply system of the fuel cell has been supplied before said load current variation.

[Claim 4]

The fuel cell power supply unit according to any one of claim 1 to claim 3 characterized in that the excess supply amount with respect to the amount of the reacting gas supplied to said fuel cell in the output equilibrium state and the characteristic value of said electric double layer capacitor are set such that the response time of the reacting gas supply system until the amount of the reacting gas supplied from the reacting gas supply system of said fuel cell to said fuel cell reaches from the supply amount immediately before the load current variation to the supply amount required to output at least the output current after the load current variation is shorter than an output assisting time by said electric double layer capacitor from the time of the load current variation until a time when the synthetic output voltage of said fuel cell and said electric double layer capacitor reaches to the voltage corresponding to an equilibrium current of said fuel cell after the load current variation.

[Claim 5]

The fuel cell power supply unit according to any one of claim 1 to claim 4 characterized in that the fuel cell power supply unit comprises a fuel cell, an electric double layer capacitor, and an output limiting device provided between the fuel cell and the electric double layer capacitor, said output limiting device functions for charging said electric double layer capacitor while limiting the output current of said fuel cell at a time of starting the power supply unit, whereas said fuel cell and said capacitor are rendered in a good electrical conducting state when a potential of said electric double layer capacitor becomes equal to or higher than an equilibrium voltage for the supply amount of the reacting gas at the time of starting said power supply unit that has been set in advance to said fuel cell.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to a power supply unit in which a fuel cell and an electric double layer capacitor are used in a good electrical conducting state.

[0002]

[Prior Art]

Conventionally, a hybrid-type power supply unit, constituted by combining an electrochemical fuel cell (hereinafter, called a "fuel cell") and an electric double layer capacitor (hereinafter, called a "capacitor"), has been known as a hybrid power source for driving an electric vehicle.

The hybrid-type power supply unit is capable of supplying power in a stable manner by compensating for the power deficiency of the fuel cell caused by the slow response of the fuel cell at the time of transitional variation of a traction motor load with energy stored in the capacitor.

[0003]

As described above, since the response of the fuel cell for the transitional variation of the load is slow, the fuel cell, even combined with a capacitor, is unable to supply sufficient energy for the sudden variation of the load, which results in entering into, what is called, the "gas-shortage state".

Accordingly, as a conventional measure to prevent a power deficiency, an output control device that is constituted by a DC/DC converter or the like is provided between a fuel cell and a capacitor in order to control the output of the fuel cell. The output control device for controlling the output of the fuel cell so as not to exceed the output corresponding to an amount of reacting gas (including air and fuel gas) supplied to the fuel cell.

[0004]

[Problems to be Solved by the Invention]

However, the output control device controls the output of the fuel cell by an ON/OFF operation of the switching element provided in the control device, and a problem arises in that the power loss due to the switching operation becomes inevitably high.

In addition, in order to cope with the output current of the fuel cell, the above output control device is designed to have a high current capacity, which causes a problem in that the size of the control device is increased.

[0005]

The present invention was made to solve the above problems, and the present invention provides a power supply unit which exhibits a very high power efficiency by using a fuel cell and a capacitor in a good electrical conducting state.

[0006]

[Means for Solving the Problem]

In order to achieve above-described objects, a fuel cell power supply unit of the present invention is a fuel cell power supply unit comprising a fuel cell (for example, the fuel cell 1 in the embodiments described later) and an electric double layer capacitor (for example, the capacitor 2 in the embodiments described later) that are placed in parallel and are used in a good electrical conducting state characterized in that the fuel cell power supply unit sets, based on a predetermined variation of load current width (for example, in the embodiments described later, the current width between the load current I_1 and I_2 that vary in a step-wise response), characteristic values of said fuel cell and a reacting gas supply system of the fuel cell (for example, in the embodiments described later, the fuel cell 1 and peripheral devices (auxiliary devices) shown in FIG. 5 including the air compressor 11; more specifically, the air compressor 11, the heat exchanger 13, the high pressure hydrogen tank 18, the electric-operated shutoff valve 19, the regulator 17, the ejector 20, the demister 21, and the humidifier 15, or the like, can be exemplified), and a characteristic value of said electric double layer capacitor, an excess supply amount (for example, in the embodiments described later, the excess supply amount at the output equilibrium) with respect to an amount of the reacting gas in an output equilibrium state where the reacting gas supplied by said reacting gas supply system of the fuel cell supplies to said fuel cell is equilibrated.

[0007]

According to the above constitution, since an oversupply amount of the reacting gas is supplied to the fuel cell in advance taking voltage drop that occurs immediately after the variation of load current into account, it is possible to prevent the fuel cell from entering into a gas-shortage state (the state in which the supply amount of the fuel gas is in

short of the requested output) when the load current is varied.

[0008]

Furthermore, in the fuel cell power supply unit described above, said fuel cell the characteristic value of said fuel cell is a fuel cell electromotive force and an internal resistance derived from a current-voltage characteristic of said fuel cell (that is, the characteristic indicated by $Vout = Vfc - (Rfc \times Ifc)$, and shown by line A with reference to FIG. 1 to FIG. 3), the characteristic value of said electric double layer capacitor is an internal resistance and a capacitance of said electric double layer capacitor, and the characteristic value of said reacting gas supply system of the fuel cell is a responsiveness to an change in a output command value to said fuel cell (for example, the air compressor response characteristic COMP shown in FIG. 9).

[0009]

By setting the excess supply amount with respect to the amount of the reacting gas in the output equilibrium state based on these characteristics, it is possible to accurately determine a voltage drop that occurs immediately after the load current variation, and it is possible to appropriately set each of the parameter described above.

[0010]

Furthermore, in the power supply unit described above, the excess supply amount supplied to said fuel cell with respect to the amount of the reacting gas in the output equilibrium state and the characteristic value of said electric double layer capacitor are set such that a synthetic output voltage of said fuel cell and said electric double layer capacitor immediately after the predetermined load current variation is given (for example, in the embodiments described later, the respective voltages V_{d1}, V_{d2}, and V_{d3} corresponding to the current I_2 derived from the current-voltage characteristic of fuel cell power supply unit 10 shown by lines D1 to D3 among various characteristic shown in FIG. 1 to FIG. 3) is higher than a voltage (for example, in the embodiments described later, each of the voltages V_{IL1}, V_{IL2}, and V_{IL3} corresponding to the output current I_{IL1}, I_{IL2}, and I_{IL3} as shown in FIG. 1 to FIG. 3) corresponding to the output current of said fuel cell that is equilibrated with the amount of the reacting gas (for example, in the embodiments

described later, the output current I_{IL1} shown in FIG. 1, the output current I_{IL2} shown in FIG. 2, and the output current I_{IL3} shown in FIG. 3) in which said reacting gas supply system of the fuel cell has been supplied before said load current variation.

[0011]

By setting the excess supply amount with respect to the amount of the reacting gas in the output equilibrium state in this manner, the allowable voltage due to the excess supply amount that has been supplied beforehand is greater than the voltage drop immediately after the electrical load varies. Thus, it is possible to prevent the fuel cell from entering into a gas shortage state immediately after the electrical load varies.

Furthermore, by applying the minimum value of the excess supply amount obtained by the setting method described above, it is possible to avoid supplying excess gas and provides efficient supply of the reacting gas.

[0012]

Furthermore, in the fuel cell power supply unit described above, the excess supply amount with respect to the amount of the reacting gas supplied to said fuel cell in the output equilibrium state and the characteristic value of said electric double layer capacitor are set such that the response time (for example, the time period between time T0 and time T3 shown in FIG. 9) of the reacting gas supply system until the amount of the reacting gas supplied from the reacting gas supply system of said fuel cell to said fuel cell reaches from the supply amount immediately before the load current variation (for example, although the response characteristic COMP shown in FIG. 9 shows the rotation speed of the air compressor 11 that equilibrates with the amount of the reacting gas supplied by the air compressor 11, the amount of the reacting gas that equilibrates with the rotation speed Nm_1 in this response characteristic COM represents the supply amount immediately before the load current variation) to the supply amount required to output at least the output current after the load current variation is shorter than an output assisting time (for example, the time period between time T0 and time T5 shown in FIG. 9) by said electric double layer capacitor from the time of the load current variation (for example, time T0 shown in FIG. 9) until a time when the synthetic output voltage (for example, the

output voltage Vout of the fuel cell capacitor 10 that is the synthetic output voltage of the fuel cell 1 and capacitor 2 shown in FIG. 9) of said fuel cell and said electric double layer capacitor reaches to the voltage (for example, output voltage V_2 shown in FIG. 9) corresponding to an equilibrium current (for example, the current I_2 shown in FIG. 9, in other words, the amount of the reacting gas that equilibrates with the rotation speed Nm_2) of said fuel cell after the load current variation (for example, time T0 shown in FIG. 9) .

[0013]

As described above, by setting the excess supply amount supplied to said fuel cell with respect to the amount of the reacting gas in the output equilibrium state and the characteristic value of said electric double layer capacitor, the output of the fuel cell reaches in a state of equilibrium, in other words, in a state in which the minimum necessary amount of the reacting gas to output a prescribed current is supplied to the fuel cell before the output current of the fuel cell power supply unit that is dependent on the capacitance of the electric double layer capacitor reaches a equilibrium value after the load current variation; thus, it is possible to prevent the fuel cell from entering into a gas shortage state.

[0014]

According to the fuel cell power supply unit of the present invention, the fuel cell power supply unit comprises a fuel cell, an electric double layer capacitor, and an output limiting device (for example, as shown in the embodiments, a current limiting device comprising a DC/DC converter and the like) provided between the fuel cell and the electric double layer capacitor, said output limiting device functions for charging said electric double layer capacitor while limiting the output current of said fuel cell (for example, when the current limiting device is a DC/DC converter, while the switching operation is performed) at a time of starting the power supply unit, whereas said fuel cell and said capacitor are rendered to in a good electrical conducting state (for example, when the current limiting device is a DC/DC converter, the fuel cell and the electric double layer capacitor are conducting while the switching operation is stopped) when a potential of said electric double layer capacitor becomes equal to or higher than an equilibrium voltage (for

example, a voltage in which the fuel cell does not enter into the gas-shortage state even when the fuel cell and the capacitor are rendered in a good conducting state) for the supply amount of the reacting gas at the time of starting said power supply unit that has been set in advance to said fuel cell.

[0015]

That is, when an electric vehicle is provided with a fuel cell power supply unit, immediately after the start of the vehicle (at the time of starting the unit), the electric power is mainly supplied by the electric double layer capacitor. Therefore, the remaining charge of the electric double layer capacitor rapidly decreases and the potential of the electric double layer capacitor becomes relatively low when compared with the potential of the fuel cell. In this state, if the electric double layer capacitor and the fuel cell are rendered in a good conducting state, a large current flows from the fuel cell to the electric double layer capacitor. Accordingly, the output of the fuel cell is rapidly drained to the electric double layer capacitor, and the potential of the fuel cell sharply drops. The fuel cell is directed into the state where the amount of the reacting gas becomes shortage for the output of the fuel cell, that is, the gas shortage state. Accordingly, while there is a large potential gap between the fuel cell and the electric double layer capacitor, it is necessary to limit the output current of the fuel cell for preventing the fuel cell from the gas shortage state.

Thus, in the present invention, while starting the vehicle wherein the potential difference between the fuel cell 1 and the capacitor 2 is large, the output current of the fuel cell 1 is controlled by the current limiting device (not shown), while charging the capacitor 2. Thereafter, when the potential of the capacitor 2 becomes equal to or higher than an equilibrium voltage for the supply amount of the reacting gas at the time of starting that has been set in advance to the fuel cell, the control of the output current from the fuel cell is stopped and the fuel cell 1 and the capacitor 2 are used in a good conducting state.

[0016]

[Embodiments of the Invention]

Hereinafter, one embodiment of the present invention will be explained with reference to the drawings.

FIG. 4 is a diagram showing a schematic diagram of an electric vehicle provided with a fuel cell power supply unit 10 according to one embodiment of the present invention. The fuel cell power supply unit 10 according to one embodiment of the present invention is installed in a vehicle and functions as a power supply for driving the vehicle. The fuel cell power supply unit 10 is a hybrid-type power supply unit comprised of a fuel cell 1 and an electric double layer capacitor (hereinafter, simply called a capacitor) 2 both of which are connected in parallel. The fuel cell power supply unit 10 supplies power to a traction motor 3 and the driving force of the traction motor 3 is transmitted to driving wheels through a transmission T/M that is constituted by an automatic transmission or manual transmission (not shown).

[0017]

In the deceleration mode of the fuel cell vehicle provided with the fuel cell power supply unit 10 according to one embodiment of this invention, when the driving force is transmitted from the driving wheel to the traction motor 3, the traction motor 3 functions as a generator and generates the so-called regenerative braking power for recovering the kinetic energy of the vehicle as electrical energy. The traction motor 3 is a permanent magnet-type three phase alternating current synchronous motor which utilizes a permanent magnet for magnetic field and the traction motor 3 is driven by the three-phase alternating current.

[0018]

The fuel cell 1 is composed of a stack of a plurality of cells, each of which is formed by inserting a polymer electrolyte membrane formed by an ion exchange film and the like between an anode and a cathode, and the fuel cell 1 is provided with a hydrogen electrode to which hydrogen is supplied and an oxygen electrode to which air containing oxygen as an oxidizing agent is supplied. The power generation of the fuel cell 1 is carried out as follows. That is, hydrogen ions produced by a catalytic reaction at the anode are transmitted to the cathode through a polymer electrolyte membrane and the

electrical power is generated by an electrochemical reaction taking place between hydrogen ions with oxygen at the cathode. The capacitor 2 is, for example, an electric double layer capacitor.

[0019]

A control device 4 is constituted as a logic circuit including a microcomputer as a main component and comprises a CPU, ROMs, RAMs, and input and output ports (components are not shown). The CPU executes prescribed calculation processes in accordance with predetermined control programs. The ROMs stored in advance control programs and control data which are required for carrying out a variety of calculation processes by the CPU, and the RAMs are used for temporarily reading and writing various types of data which are necessary for executing various calculation processes. The input and output ports receive signals detected by various sensors, such as a remaining charge monitoring device, and output signals to predetermined portions for controlling driving states of the fuel cell power supply unit 10 and every component of the fuel cell vehicle.

[0020]

For example, the control device 4 calculates a target generation amount based on signals inputs as parameters such as an accelerator pedal opening signal concerning depression operation of the accelerator pedal by a driver, signals of the vehicle speed and a rotation speed of the motor, and signals of sensors associated with energy consumption of electrical auxiliary devices. The target generation amount obtained as described above is transmitted to the fuel cell power supply unit 10 and the target output is transmitted to the traction motor 3. The remaining charge of the capacitor 2 is calculated based on signals from sensors such as a voltage sensor or a current sensor (not shown), and the remaining charge of the capacitor is used as one of the parameters for controlling the fuel cell power supply unit 10.

[0021]

In order to drive the fuel cell power supply unit 10 according to the one embodiment of the present invention, various components are used in addition to the above-described constituting elements, such as an inverter for converting the direct current

supplied from the fuel cell power supply unit 10 to three phase alternative current and supplying the three-phase alternating currents, sensors for detecting voltage, current, and temperatures of the fuel cell power supply unit 10, and switching elements for switching based on signals input from the control device 4. Explanations of these constituting elements are omitted for better understanding of the structure and operation of the fuel cell power supply unit 10.

[0022]

Although not shown in the block diagram of FIG. 4, the fuel cell 1 is required to provide peripheral devices in addition to the fuel cell body composed of the cell stack structure for executing power generation by the fuel cell 1. FIG. 5 is a block diagram showing the structure of a fuel cell system 30 composed of the fuel cell 1 and the peripheral devices.

[0023]

As shown in FIG. 5, an air compressor 11 connected to the oxygen electrode side of the fuel cell 1 supplies air not only to the oxygen electrode but also to the regulator 17 as a signal pressure. Thus, a rotation speed command value N is input from the control device 4 to the motor (not shown) which is used for driving the air compressor 11. The motor drives the air compressor 11 based on the rotation speed command value N and the air compressor thereby compresses externally introduced air for supplying to a heat exchanger 13. .The compressed air is cooled by the heat exchanger 13 and dust is removed by a filter.

[0024]

The air is supplied to a humidifier 15, and the humidified air supplied to the fuel cell 1 is used for the above-described electrochemical reaction. After this, air is exhausted from the fuel cell after passing through a pressure regulating valve 16 provided for regulating the pressure of the air to path through the fuel cell 1.

A regulator 17 (also called a proportional pressure regulator) regulates the pressure of hydrogen supplied from a high pressure hydrogen tank 18 to the fuel cell 1 based on the air pressure (pilot signal) supplied from the air supply side. As described

above, the air pressure and the hydrogen pressure to be supplied from the air supply side and the hydrogen supply side are controlled by a regulator 17 so as to be balanced.

[0025]

Since the pressure of hydrogen supplied from the high pressure hydrogen tank 18 is high, the pressure of hydrogen is reduced by a regulator 17 after being firstly reduced by an electric-operated shutoff valve 19 and hydrogen after the pressure reduction is supplied to a humidifier 15 through an ejector 20. After humidifying by the humidifier 15, hydrogen is supplied to the fuel electrode of the fuel cell 1. After humidifying by the humidifier 15, hydrogen is supplied to the fuel electrode of the fuel cell 1. After being used for the electrochemical reaction, hydrogen is discharged from the fuel cell 1 to a demister 21. The discharged gas supplied into the demister 21 is subjected to gas - liquid separation and hydrogen in the gas phase state is circulated to the supply side of hydrogen through an ejector 20 to be reused.

A purge valve 22 is provided at the exhaust side of hydrogen for discharging water held in the fuel cell and the demister.

Note that the above-described electric-operated shutoff valve 19 also has a function to cutoff the hydrogen supply from the high pressure hydrogen tank 18.

[0026]

Water pumps 40 and 41 are used for circulating cooling water after being cooled by heat dissipation in radiators 23 and 24 in the auxiliary devices/control devices for controlling the temperature of the auxiliary devices/control devices below a predetermined temperature. In the present system, the water pump 40 is provided for cooling the fuel cell 1, the auxiliary devices/control devices and for heating the fuel supply side, and the water pump 41 is provided for cooling the air supply devices.

[0027]

The auxiliary devices/control devices output a driving signal for the air regulator 16 and the electric power generation output of the fuel cell is controlled by opening or closing the air supply to the fuel cell 1 or by regulating the amount of air supply to the fuel cell 1.

[0028]

In the above, the structure of the fuel cell power supply unit 10 has been explained. Next, the variation of the reacting gas amount to be supplied to the fuel cell 1 is described below when the fuel cell power supply unit 10 must respond to a specific variation of load current.

[0029]

FIG. 6 is a diagram showing an equivalent circuit of the fuel cell power supply unit 10 according to one embodiment of the present invention. In this figure, Vfc denotes an electromotive force of the fuel cell, Rfc denotes an internal resistance of the fuel cell, and Ifc denotes a current flowing in the fuel cell. In the capacitor 2 block, Vcap denotes an electromotive force, Rcap denotes an internal resistance, and Icap denotes a capacitor current. Vout denotes an output voltage of the fuel cell power supply unit 10 and Iout denotes a current flowing in the fuel cell power supply unit 10.

[0030]

In the fuel cell power supply unit 10 shown by the above-described equivalent circuit, an operation is described below when the electrical load varies. For the convenience of explanation, a case will be described in which the load current varies stepwise from I_1 to I_2. Note that the electrical load will not vary stepwise as for actual vehicles.

[0031]

When such a load current takes place, the control device 4 requires of the fuel cell power supply unit 10 to output power corresponding to the variation of load current, that is, an output corresponding to the load current I_2. However, as shown in FIG. 5, the output corresponding to the variation of electrical current is not generated until the control device 4 transmits a rotation speed command value N to the motor for driving the air compressor 11 as the auxiliary device, the rotation speed of the compressor increases, the reacting gas supply increases, and the electrochemical reaction takes place in the fuel cell 1. Thus, it takes time for the fuel cell to generate electric power corresponding to the variation of load current.

Accordingly, during the delayed period of the fuel cell for responding to the variation of electrical load, the capacitor 2 connected in parallel to the fuel cell 1 can supply a necessary amount of electric power to the traction motor 3 for responding to the variation of electrical load.
However, as shown in FIG. 6, because of the internal resistance Rcap of the capacitor 2, a voltage drop will be generated due to the increased current by supplying electric power. FIG. 7 shows a time dependent variation of the output voltage Vout (response characteristics) of the fuel cell power supply unit 10 when the load current Iout varies stepwise from I_1 to I_2. FIG. 7(a) shows the response characteristics of the output voltage and FIG. 7 (b) shows the response characteristics of the load current.

[0032]

As shown in this figure, before the variation of electrical load (before time t_0), the voltage corresponding to the load current I_1 is at an equivalent voltage of $Vout = Vfc - (Rfc \times I_1)$.

When the load current varies at time t_0, the capacitor starts supplying the electric power corresponding to the variation of electrical load. However, the supplying of the electric power caused rapid increase of the current Icap and the increased current originates a voltage drop ($\Delta V = Rfc \times Ifc_2 = Rcap \times Icap_2$). Thereafter, the output voltage Vout gradually decreases due to the discharge of the capacitor 2, and the output voltage Vout reaches an equilibrium state when the output voltage becomes $Vout = Vfc - (Rfc \times I_2)$. Accordingly, the time required to converge to the equilibrium state of $Vout = Vfc - (Rfc \times I_2)$ becomes longer when the capacitance of the capacitor 2 is larger and thus the gradient is smaller. The voltage drop immediately after the variation of electrical load is smaller when the internal resistance of the capacitor 2 is smaller.

[0033]

When the voltage drop takes place immediately after the variation of electrical load, that is, when the output voltage drops when the fuel cell 1 is responding to the variation of electrical load, the reacting gas for the fuel cell 1 becomes shortage, that is, the fuel cell falls into the gas shortage state for the output voltage.

When such a gas shortage state continues or when the gas shortage state occurs frequently, the water content of the polymer electrolyte membrane, made of an ion exchange membrane, becomes shortage, and the resistance for hydrogen ions to pass through the polymer membrane becomes high, which deteriorates the polymer membrane and also shortens the service life of the fuel cell.

In order to prevent such a gas shortage state, it is necessary to supply the amount of reacting gas corresponding to the voltage drop due to the internal resistance (an excess supply amount). In the following, this will be explained with reference to FIG. 8.

[0034]

The target generation amount corresponding to the load output shown in FIG. 8 (a) must be set to a value that is obtained by adding an excess supply amount required for the voltage drop at the transitional response described above, as shown in FIG. 8 (b). Therefore, it is possible to prevent an entry into a gas shortage state even when a voltage drop occurs at time t_0.

Furthermore, the capacitance of the capacitor 2 must be set such that the actual response of the fuel cell shown by the solid line in FIG. 8 (c) is equal to or less than the maximum response line of the fuel cell that is shown by the dotted line in the same figure. In other words, the capacitor 2 having such capacitance and the fuel cell 1 must be connected in parallel to constitute the fuel cell power supply unit 10. This is because during the time period when the output of the fuel cell power supply unit 10 is dependent on the output of the capacitor 2 immediately after the electrical load varies, the output of the fuel cell 1 must be prevented from reaching to the output limit of the fuel cell 1. Furthermore, the output gradually reaches to a state of equilibrium as shown in the same figure because of the characteristic of the capacitance of the capacitor 2. As described previously with reference to FIG. 7, the greater the capacitance of the capacitor 2, the gentler this gradient becomes.

FIG. 8 (d) shows the output of the capacitor 2 when the electrical load output varies, similar to the case shown in FIG. 8 (a). It is noted that this gradient also varies as the capacitance of the capacitor 2 changes.

[0035]

As described above, a voltage drop occurs immediately after the electrical load varies, and in order to prevent fuel cell 1 from entering into a gas shortage state due to this voltage drop, a target generation amount that is determined by adding the excess supply amount must be set beforehand.

This oversupply amount is determined by the internal resistance and the capacitance of the capacitor which constitutes the fuel cell power supply unit 10, a prescribed width of the variation of load current, and characteristic values of the fuel cell 1 and the fuel cell system 30.

[0036]

Examples of the above-described characteristic values of the fuel cell include the output power and the internal resistance of the fuel cell 1 derived from the current-voltage characteristic (Vout = Vfc - (Rfc × Ifc)), and an example of the characteristic value of the fuel cell system 30 includes the response speed of the reacting gas supply system to the fuel cell, which will be described later.

In the following, a method of setting the excess supply amount will be described in a concrete manner with reference to FIG 1 to FIG 3.

[0037]

A method of setting the oversupply amount in the case in which the internal resistance Rcap of the capacitor 2 is higher than the internal resistance Rfc of the fuel cell 1 is described with reference to FIG 1.

In this figure, as shown by the line A which shows the current-voltage characteristic of the fuel cell 1, a higher output voltage is obtained when the output current is low and the output voltage decreases as the output voltage increases. When the output voltage and the output current are below the line A, the fuel cell is assumed to be in the gas shortage state.

The line B1 in this figure shows a current-voltage characteristic of the fuel cell power supply unit 10 when the maximum amount of the reacting gas is set and supplied to the fuel cell 1 prior to the variation of load current. Response characteristics of the fuel

cell power supply unit 10 provided with a fuel cell 1 having the current-voltage characteristic shown above is described below when the load current varies by stepwise from I_1 to I_2.

[0038]

Assume for example, that the supply amount of the reacting gas to the fuel cell 1 before the load current varies is set at an amount in which the fuel cell 1 is capable of outputting a current I_{L11} ($I_1<I_{L11}<I_2$), that is, when the supply amount of the reacting gas makes the fuel cell reach an equilibrium output current I_{L11}. This supply amount corresponds to the amount of the reacting gas capable of outputting the current of I_{L11} - I_1.

In the above case, the output power of the fuel cell 1 is not sufficient to respond to the variation of electrical load, so the capacitor 2 assists the output power. That is, the output power of the fuel cell power supply unit 10 is dependent on the output of the capacitor until the fuel cell 1 can supply the output power corresponding to the variation of electrical load, which corresponds to the transition time of the fuel cell for responding to the variation of electrical load.

[0039]

As a result, when the output current is in a region ranging from I_1 to I_{L11}, the current-voltage characteristic of the fuel cell power supply unit 10 varies along the line B1 in FIG. 1, while when the output current is beyond I_{L11} the fuel cell power supply unit 10 shows the current-voltage characteristic of the capacitor as shown by the line D1. Note the current-voltage characteristic of the capacitor shown by the line Dl is expressed by, Vout = Vcap - (Icap × Rcap), wherein Rcap > Rfc and Vcap is constant.

[0040]

The output voltage of the fuel cell power supply unit 10 at an output current 12 immediately after the variation of load current can be obtained as V_{d1} from the line D1, and the voltage drop ΔV of the fuel cell power supply unit 10 when the variation of load current is applied in a stepwise manner can be obtained as the voltage by subtracting the output voltage V_{d1} at I_2 from the output voltage V_1 at I_1.

In contrast, since it is possible for the fuel cell 1 to output an output voltage

which corresponds to an output current, equilibrated with the amount of the reacting gas supplied before the variation of load current, the output voltage is obtained as V_{LI1} from the line A. Thus, an allowable voltage drop ΔV' for the fuel cell 1 immediately after the variation of electrical load is obtained by subtracting the output voltage V_{LI1} at I_{LI1} from the output voltage V_1 at I_1, as shown in FIG. 1.

[0041]

Accordingly, since the allowable voltage drop ΔV', which is estimated from the amount of reacting gas supplied to the fuel cell 1 before the variation of load current, is larger than the voltage drop ΔV immediately after the variation of electrical load, it is possible to prevent the fuel cell from entering into the gas shortage state.

As described above, it becomes possible to prevent the fuel cell from entering into the gas shortage state by setting an excess supply amount of the reacting gas so as to exceed the equilibrated supply amount before the variation of load current to be able to generate an output voltage V_{d1} of the fuel cell power supply unit 10 above the voltage V_{LI1}, which corresponds to the output voltage of the fuel cell 1 equilibrated with the supply amount of the reacting gas before the variation of load current.

[0042]

Next, a consideration is described when the internal resistance Rcap of the capacitor 2 is equal to the internal resistance Rfc of the fuel cell 1 with reference to FIG. 2.

The line A in FIG. 2 is the same current-voltage characteristic of the fuel cell 1 as that shown in FIG. 1.

The line B2 in FIG. 2 shows a current-voltage characteristic of the fuel cell power supply unit 10 when the maximum amount of the reacting gas is set and is supplied to the fuel cell 1 prior to the variation of load current. As shown, a gradient of the current-voltage characteristic B2 is more gentle than that of the characteristic B1, since the internal resistance Rcap of the capacitor 2 is equal to the internal resistance Rfc of the fuel cell. A response characteristic of the fuel cell power supply unit 10 is described below when the load current is varied stepwise from I_1 to I_2.

[0043]

Assume, for example, that the excess supply amount of the reacting gas to the fuel cell before the load current varies is set at an amount in which the fuel cell 1 is capable of outputting a current I_{LI2} ($I_1 < I_{LI2} < I_2$), that is, when the supply amount of the reacting gas makes the fuel cell reach an equilibrium output current I_{LI2}, the output power of the fuel cell is not sufficient so as to respond to the variation of load current so that the capacitor 2 assists the output power as the fuel cell power supply unit 10. Note that the excess supply amount corresponds to the amount of the reacting gas which enable to output the current I_{LI2} - I_1. Thus, when the output current I is a region ranging from I_1 to I_{LI2}, the current-voltage characteristic of the fuel cell power supply unit 10 is modified to the synthetic current-voltage characteristics composed of both characteristics of the fuel cell 1 and the capacitor 2, which is shown by line B2 in FIG. 2. In contrast, when the output current is in a region above I_{LI2}, the output voltage of the fuel cell power supply unit 10 is represented by the current-voltage characteristic of the capacitor, that is, as shown by line D2 in FIG. 2.

[0044]

The current-voltage characteristic of the capacitor 2 is linear as shown by the line C2, following the equation of Vout = (Icap × Rcap), wherein the Rcap is constant. In addition, since Rcap = Rfc, the gradient of the line D2 is identical with that of the current-voltage characteristic A.

The output voltage of the fuel cell power supply unit 10 at a current I_2 is obtained as V_{d2} from the line D2. Therefore, the voltage drop ΔV due to the internal resistance Rcap of the capacitor 2 when the load current varies stepwise from I_1 to I_2 can be obtained as shown in FIG. 2, as explained similarly for FIG. 1.

[0045]

The output voltage corresponding to an output current which is in equilibrium with the amount of reacting gas supplied to the fuel cell 1 before the variation of the load current is obtained as V_{LI2} from the line A, and it is estimated that the fuel cell 1 can output the output voltage to the extent of V_{LI2}. The allowable output voltage variation $\Delta V'$ for the fuel cell 1 when the load current varies from I_1 to I_2 is obtained as shown in

FIG. 2.

As a result, even if the voltage drop ΔV occurs due to the internal resistance of the capacitor 2 after the variation of electrical load, an excess amount of reacting gas is supplied in advance to the fuel cell 1 to cover the voltage drop, so that it is possible to prevent the fuel cell vehicle from entering into a gas shortage state.

[0046]

Next, an explanation is provided below when the internal resistance of the capacitor Rcap is lower than the internal resistance Rcap of the fuel cell 1 with reference to FIG. 3.

The line A in FIG. 2 is the same current-voltage characteristic of the fuel cell 1 as that shown in FIG. 1. In addition, the line B3 in FIG. 3 shows a current-voltage characteristic of the fuel cell power supply unit 10 when the maximum amount of the reacting gas is set and is supplied to the fuel cell 1 prior to the variation of load current. Since the internal resistance Rcap of the capacitor 2 is lower than the internal resistance Rfc of the fuel cell 1, the gradient of the current-voltage characteristic B3 becomes more gentle that that of the line B2.

A response characteristic of the fuel cell power supply unit 10 is described below when the load current is varied stepwise from I_1 to I_2.

[0047]

In the above case, when, for example, the excess supply amount to the fuel cell 1 before the load current varies is set at a value in which the fuel cell 1 is capable of outputting the output current I_{LI3} ($I_1 < I_{LI3} < I_2$), that is, when the supply amount of the reacting gas makes the fuel cell reach an equilibrium output current I_{LI3}, since the output power from the fuel cell 1 is not sufficient in a region above I_{LI3}, similarly in the case of FIG. 1, the output power is assisted by the capacitor 2. The excess supply amount of the reacting gas corresponds to that for outputting a power of I_{LI3} - I_1.

When the current is in a range from I_1 to I_{LI3} the current-voltage characteristic of the fuel cell power supply unit 10 is thereby governed by the synthetic current-voltage characteristics of both the fuel cell 1 and the capacitor 2, which is shown by line B3 in FIG.

3. In contrast, when the current is above I_{LI3}, the current-voltage characteristic of the fuel cell power supply unit 10 is governed by that of the capacitor 2, shown by line D3.

[0048]

The current-voltage characteristic of the capacitor shown by line C3 is linear and is expressed by an equation, Vout = Vcap - (Icap × Rcap), wherein Vcap is constant. Since Rcap < Rfc, the line D3 show the most gentle gradient among current-voltage characteristic lines, shown in FIG. 1 and FIG. 2.

The output voltage at a current I_2 of the fuel cell power supply unit 10 is obtained as V_{d3} from the line D3. Therefore, the voltage drop ΔV due to the internal resistance Rcap of the capacitor 2 when the load current varies stepwise from I_1 to I_2 can be obtained as shown in FIG. 3, as explained similarly for FIG. 1.

[0049]

In contrast, the output voltage corresponding to an output current which is equilibrated with the amount of the reacting gas supplied to the fuel gas before the variation of load current is obtained as V_{LI3} from the line A, the fuel cell 1 is capable of outputting the power until this output voltage. The allowable output voltage variation ΔV' for the fuel cell 1 when the load current varies from I_1 to I_2 is obtained as shown in FIG. 3.

As a result, after the variation of electrical load, even if a voltage drop ΔV is generated due to the internal resistance Rcap of the capacitance, since the reacting gas is supplied to the fuel cell 1 in excess in advance for covering the voltage drop, it is possible to prevent the vehicle from entering into the gas shortage state.

[0050]

In the above, the method of setting the excess supply amount in the cases in which the internal resistance Rcap of the capacitor 2 is greater than the internal resistance Rfc of the fuel cell 1, in which the two values are the same, and in which the internal resistance Rcap of the capacitor 2 is smaller than the internal resistance Rfc of the fuel cell 1 have been explained with reference to FIG. 1 to FIG. 3. Since the voltage drop of the output of the fuel cell power supply unit 10 immediately after the load current variation increases with an increase in the internal resistance Rcap of the capacitor 2, the excess

supply amount will increase accordingly. Thus, if it is desired to reduce the excess supply amount, this may be accomplished by selecting a capacitor 2 whose internal resistance is low.

In addition, in the cases shown in FIGS. 1 to 3, if the minimum value of excess reacting gas among the amounts adopted in the above cases is selected, it is possible to avoid supplying too much reacting gas and to supply the reacting gas efficiently.

[0051]

Next, the response characteristic of the fuel cell power supply unit 10 when the load current is varied is shown in FIG. 9. As shown in the figure, the require torque Ap varies from I_1 to I_2 from time T1 to time T2 according to the variation of the depression amount of the accelerator pedal, when a driver depresses the accelerator pedal. In addition, following to the variation of the required torque Ap, the motor required current Imot varies from I_1 to I_2 accompanying a small delayed time.

[0052]

As a representative response characteristic COMP of the reacting gas supply amount to the fuel cell, the rotation speed of the compressor 11 which is in equilibrium with the reacting gas supply amount supplied by the compressor 11 is shown. The rotation speed which is in equilibrium with the reacting gas supply amount at the time T0 before the variation of load current is Nm_1. The rotation speed starts to vary at time T_1 after a certain time delay, and reaches a rotation speed Nm_2 corresponding to the output current I_2 after the variation of load current at time T3 and the rotation speed further increases until it reaches an equilibrium rotation speed corresponding to a value including an excess reacting gas supply amount in addition to the rotation number Nm_2 after the variation of load current.

[0053]

The output current of the fuel cell 1 starts increasing after the variation of load current with the increasing amount of the reacting gas, and at time T4, the output current reaches an equilibrium current I_2 after the variation of load current, the fuel cell outputs a higher current than I_2 for a while, and thereafter the output current converges to the current

I_2.

On the other hand, the capacitor 2 discharges electric power for assisting the output power while the output power of the fuel cell 1 is shortage. The capacitor 2 starts discharging the power at time T1 and the output current of the capacitor 2 varies along the variation of the output current of the fuel cell 1 until the output current of the fuel cell 1 reaches the equilibrium state. As a result, the synthetic output current Iall of the output currents of the fuel cell 1 and the capacitor 2 varies so as to satisfy the required torque Ap.

[0054]

On the other hand, the synthetic output voltage Vout of the fuel cell 1 and the capacitor 2 starts decreasing from time T1 and reaches an equilibrium voltage after the variation of load current at time T5.

As shown in FIG. 9, when a variation of load current is applied, the amount of the reacting gas supplied from reacting gas supply system of the fuel cell varies from the supply amount of the reacting gas immediately before the variation of load current at time T0, that is, the supply amount equilibrated with the rotation speed Nm_1 of the compressor 11 to a supply amount (for example, supply amount corresponding to the rotation speed Nm_2) required to output at least an output current (for example, I_2) after the variation of load current at time T3. In the above case, the response time of the reacting gas supply unit is the time period between T0 and T3. Note that the above-described response time corresponds the changing time of the synthetic output voltage Vout of the fuel cell 1 and the capacitor 2 from a equilibrium voltage at T0 reaches the output voltage V_2 corresponding to an equilibrium current I_2 after the variation of load current. The excess amount of the reacting gas to be supplied to the fuel cell 1 and the capacitor characteristics is determined such that the output assistance operation period of the capacitor 2, that is, the time period between T0 and T5, is longer than the above-described time period between T0 and T3.

[0055]

As shown above, when a subscribed variation of load current is given to the fuel cell power supply unit 10, it is possible to avoid the gas shortage state of the fuel cell 1 by

setting the necessary amount of the reacting gas supplied to the fuel cell 1 with respect to the amount of the reacting gas equilibrated before the variation of load current and the capacitor characteristics such that the supply amount of the reacting gas to the fuel cell 1 reaches an amount required for outputting at least an equilibrium current after the variation of load current before the synthetic output voltage of the fuel cell 1 and the capacitor 2 reaches a voltage corresponding to an equilibrium current after the variation of load current.

[0056]

As described above, an explanation is provided that the fuel cell 1 and the capacitor 2 in a good electrical conducting state is used for the fuel cell power supply unit according to one embodiment of the present invention. However, in practice, a current limiting device (not shown) is provided between the fuel cell 1 and the capacitor 2. Hereinafter, the current limiting device is described with reference to FIG. 1. Hereinafter, the current limiting device is described with reference to FIG. 1.

[0057]

For example, immediately after the start of the vehicle, for example, the electric power is mainly supplied by the capacitor 2.

Therefore, the remaining charge of the capacitor 2 rapidly decreases and the potential of the capacitor 2 becomes relatively low when compared with the potential of the fuel cell 1. If the capacitor 2 in this state is connected to the fuel cell 1 in a good conducting state, a large current flows from the fuel cell 1 to the capacitor 2 and the potential of the fuel cell also decreases rapidly.

[0058]

The fuel cell 1 is directed into the state where the amount of the reacting gas becomes shortage, that is, the gas shortage state. Accordingly, while there is a large potential gap between the fuel cell 1 and the capacitor 2, it is necessary to limit the output current of the fuel cell 1 for preventing the fuel cell 1 from the gas shortage state. Thus, in the present invention, while starting the vehicle wherein the potential difference between the fuel cell 1 and the capacitor 2 is large, the output current of the fuel cell 1 is

controlled by the current limiting device (not shown), while charging the capacitor 2. Thereafter, when the potential of the capacitor 2 becomes equal to or higher than an equilibrium voltage for the supply amount of the reacting gas at the time of starting that has been set in advance to the fuel cell, the control of the output current from the fuel cell is stopped and the fuel cell 1 and the capacitor 2 are used in a good conducting state.

Consequently, at the starting period, a current limiting device, constituted by a device such as a DC/DC converter, is provided between the fuel cell 1 and the capacitor 2, similarly to the conventional case. A switching device provided in the current limiting device thereby limits the output current from the fuel cell 1 by its ON/OFF operation. However, after the vehicle has been started, and the vehicle arrives at the state wherein the potential difference between the fuel cell 1 and the capacitor 2 becomes less than a predetermined potential difference, it becomes unnecessary to limit the output current from the fuel cell, the current limiting device stops its operation, and the fuel cell 1 and the capacitor enter in a good conducting state.

As described above, although the present unit practically includes the current limiting device between the fuel cell 1 and the capacitor 2, the current limiting device does not execute the switching operation when the power supply unit is used in the actual driving operations as described above. Thus, in the actual driving operation, the fuel cell power supply unit operates as if the current limiting device does not exist.

[0059]

Although some embodiments of the present invention have been described with reference to the attached drawings, this invention is not limited to the embodiments described above. Variants thereof can be envisaged which do not exceed the scope of the present invention.

[0060]

[Advantageous Effects of the Invention]

As described above, according to the fuel cell power supply unit of the present invention, since excess supply amount is set based on the predetermined variation of current load width, and the characteristic values unique to the fuel cell and the fuel cell

system, the internal resistance and the capacitance of the capacitor, the fuel cell is prevented from entering into a gas shortage state caused by a voltage drop that occurs immediately after the load current is varied. In addition, by using the fuel cell and capacitor in a good conducting state, an effect is obtained that a fuel cell power supply unit has a high power output efficiency.

[0061]

Furthermore, according to the fuel cell power supply unit of the present invention, since the excess supply amount is set according to the predetermined variation of current load width, the electrical power and the internal resistance of the fuel cell that are derived from the current-voltage characteristic of the fuel cell, and the response speed characteristic of the fuel cell, it is possible to accurately determine a voltage drop that occurs immediately after the load current variation, and it is possible to appropriately set each of the parameter described above. This makes it possible to improve performance of the fuel cell power supply unit.

[0062]

Furthermore, according to the fuel cell power supply unit of the present invention, by setting the excess supply amount such that the output voltage of the fuel cell power supply unit immediately after the load current variation is given is higher than the voltage corresponding to the excess supply amount that has been provided to the fuel cell before the load current is varied, the allowable voltage drop due to the excess supply amount that has been supplied beforehand is greater than the voltage drop immediately after the electrical load varies. Therefore, it is possible to prevent the fuel cell from entering into a gas shortage state immediately after the electrical load varies, and an effect is obtained in that supplying excess gas is avoided and that efficient supply of the reacting gas is achieved.

[0063]

Furthermore, according to the fuel cell power supply unit of the present invention, the excess supply amount with respect to the amount of the reacting gas supplied to the fuel cell in the output equilibrium state and the characteristic value of the electric double

layer capacitor are set such that the response time of the reacting gas supply system until the amount of the reacting gas supplied from the reacting gas supply system of the fuel cell to the fuel cell reaches from the supply amount immediately before the load current is varied to the supply amount required to output at least the output current after the load current variation is shorter than the output assisting time by the electric double layer capacitor from the time of the load current variation until the time when the synthetic output voltage of the fuel cell and the electric double layer capacitor reaches to the voltage corresponding to the equilibrium current of the fuel cell after the load current variation. Therefore, the reacting gas is supplied efficiently to the fuel cell while preventing the fuel cell from being gas shortage, and an effect is obtained that a fuel cell power supply unit has a high power output efficiency.

[0064]

According to the fuel cell power supply unit of the present invention, a current limiting device provided between the fuel cell and the capacitor, functions for charging the capacitor while limiting the output current of the fuel cell at a time of starting the power supply unit, whereas the fuel cell and the capacitor are rendered in a good electrical conducting state when a potential of the electric double layer capacitor becomes equal to or higher than an equilibrium voltage for the supply amount of the reacting gas at the time of starting the power supply unit that has been set in advance to the fuel cell. As described above, since the fuel cell and the capacitor can be rendered in a good electrical conducting state after starting of the power supply unit without using the current limiting device, it is possible to avoid the power loss by the current limiting device and it is also possible to supply the power to the load effectively.

[Brief Description of the Drawings]

[FIG. 1] A diagram showing a example of the current-voltage characteristic of a fuel cell according to one embodiment of the present invention.

[FIG. 2] A diagram showing an example of the current-voltage characteristic of a fuel cell according to this embodiment of the present invention.

[FIG. 3] A diagram showing an example of the current-voltage characteristic of a fuel

cell according to this embodiment of the present invention.

[FIG. 4] A diagram showing a schematic diagram of an electric vehicle provided with a fuel cell power supply unit according to this embodiment of the present invention.

[FIG. 5] A diagram showing the fuel cell and peripheral devices therefor according to this embodiment and its peripheral devices.

[FIG. 6] A diagram showing an equivalent circuit of the fuel cell power supply unit according to this embodiment of the present invention.

[FIG. 7] A diagram showing the voltage response characteristics and current response characteristics of the fuel cell power supply unit according to this embodiment of the present invention.

[FIG. 8] A diagram showing various output characteristics of the fuel cell power supply unit according to this embodiment of the present invention.

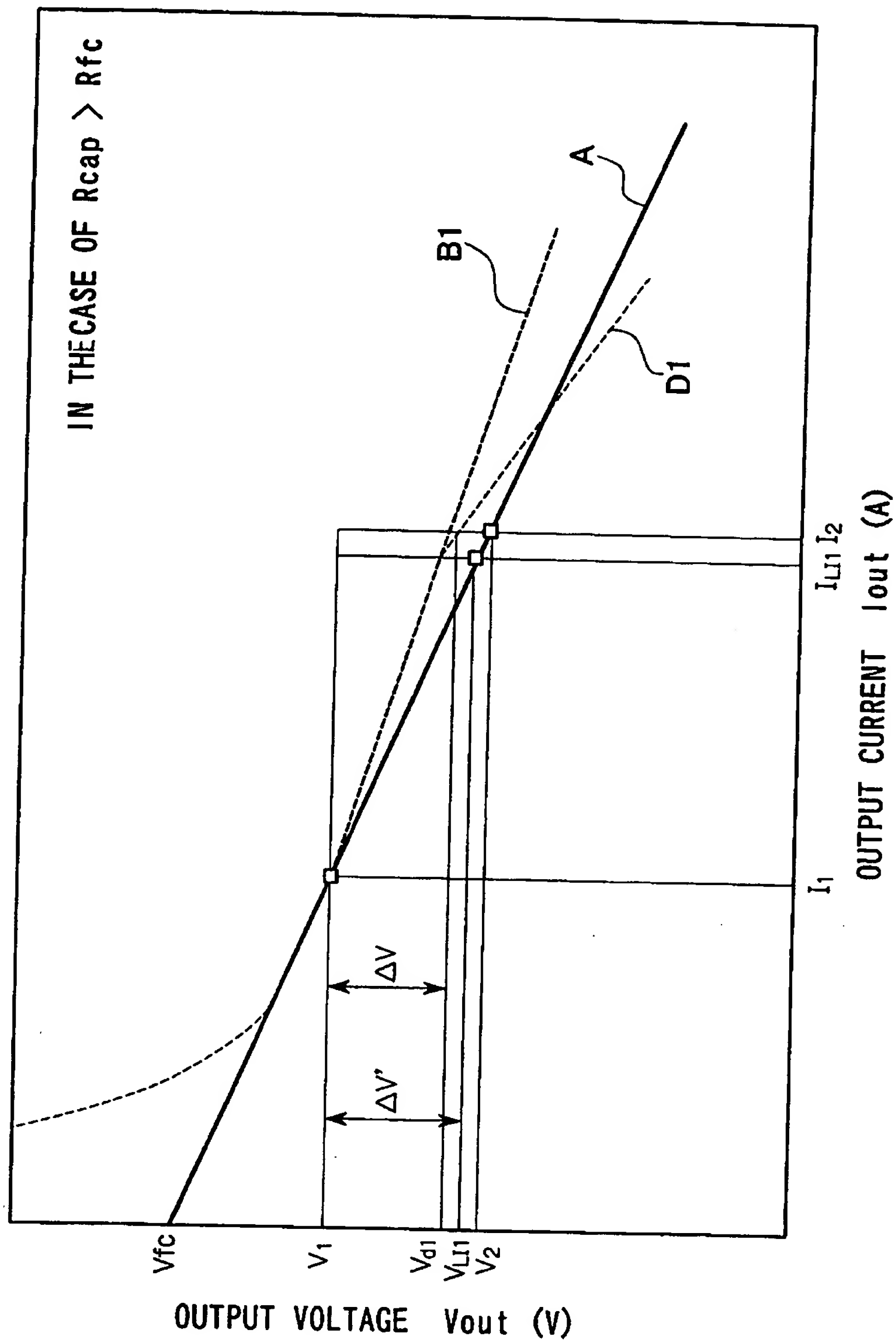
[FIG. 9] A diagram showing various response characteristics of the fuel cell power supply unit according to this embodiment of the present invention.

[Description of the Reference Symbols]

1 ... fuel cell, 2 ... capacitor (electric double layer capacitor), 3 ... traction motor, 4 ... control device, 10 ... fuel cell power supply unit, 11 ... air compressor

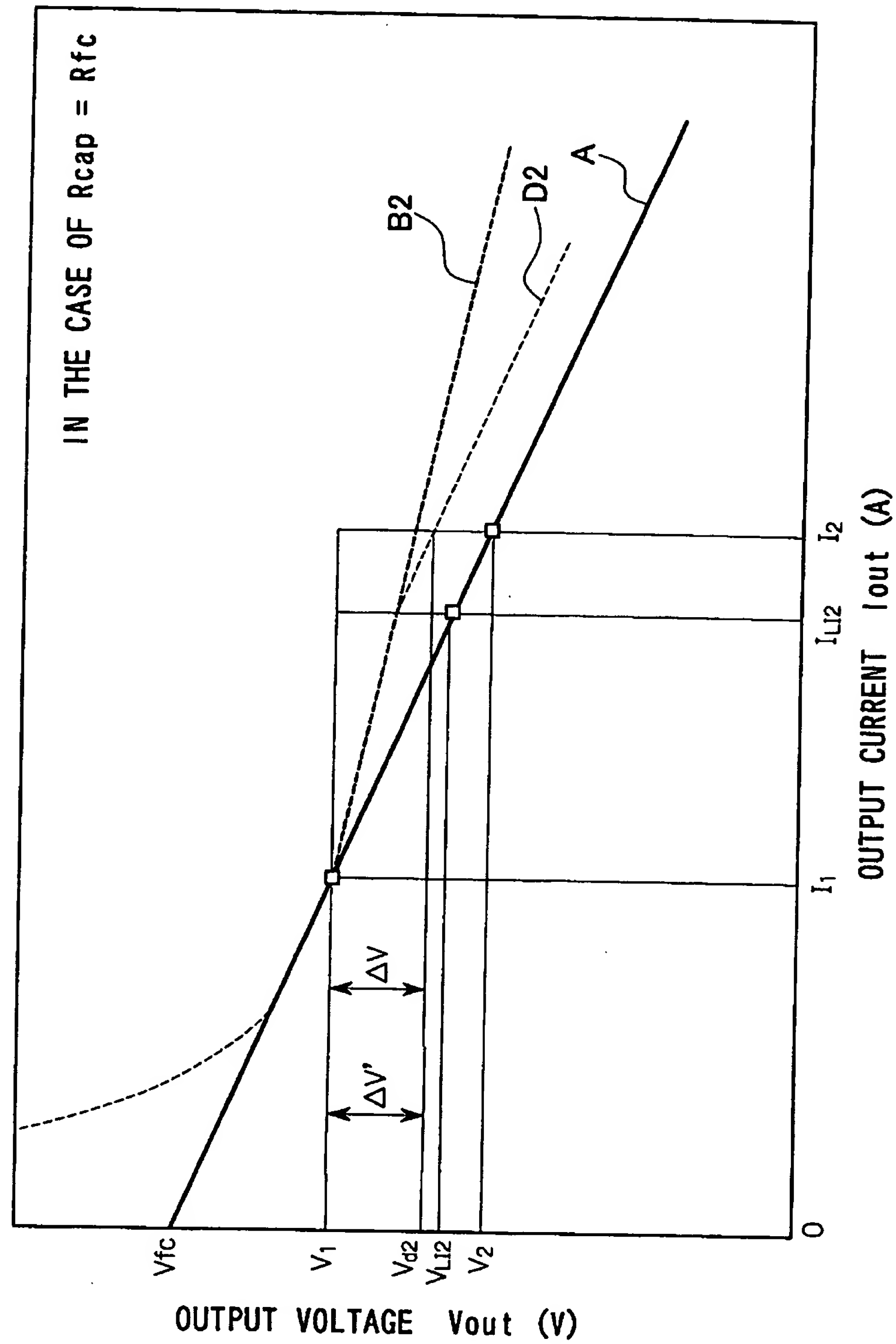
Docket Number J85244A1
[Document Type] Drawing

[FIG. 1]



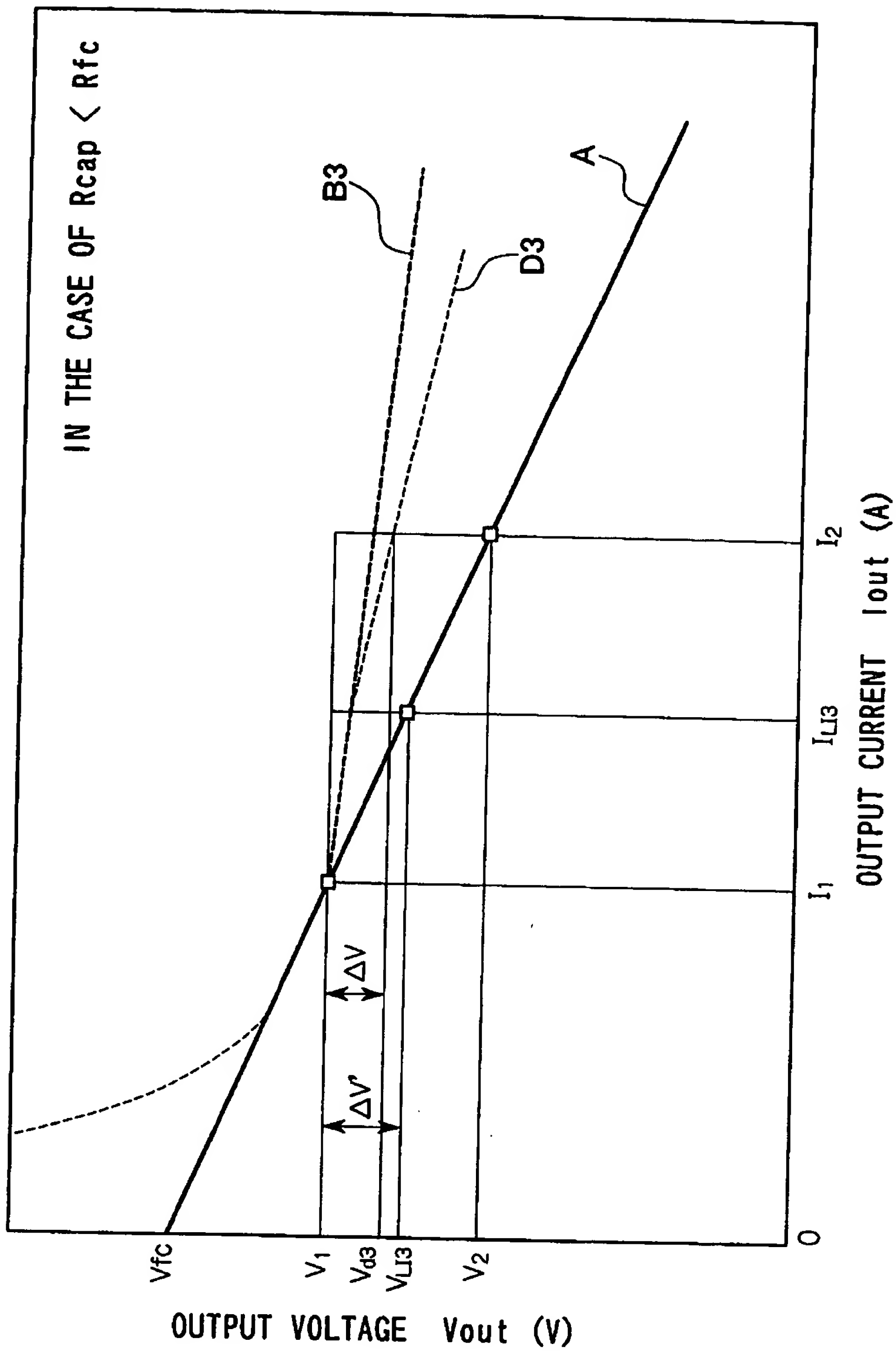
Docket Number J85244A1
[Document Type] Drawing

[FIG. 2]



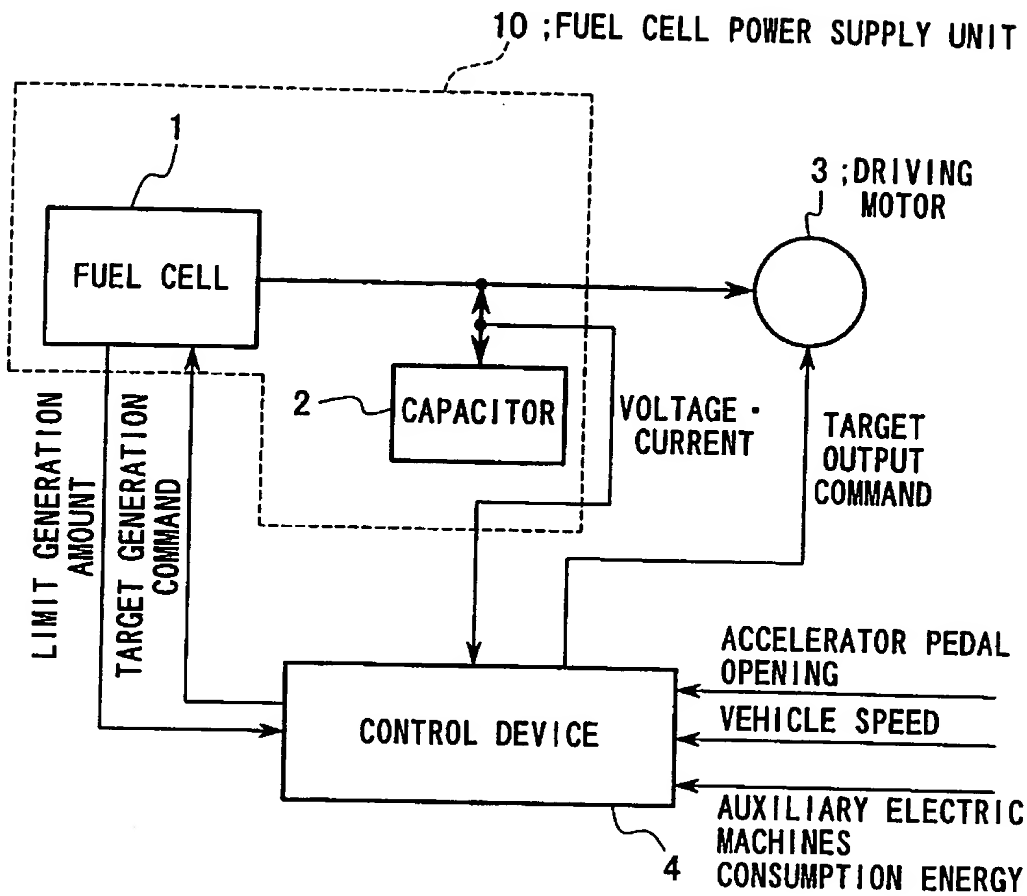
Docket Number J85244A1
[Document Type] Drawing

[FIG. 3]



Docket Number J85244A1
[Document Type] Drawing

[FIG. 4]



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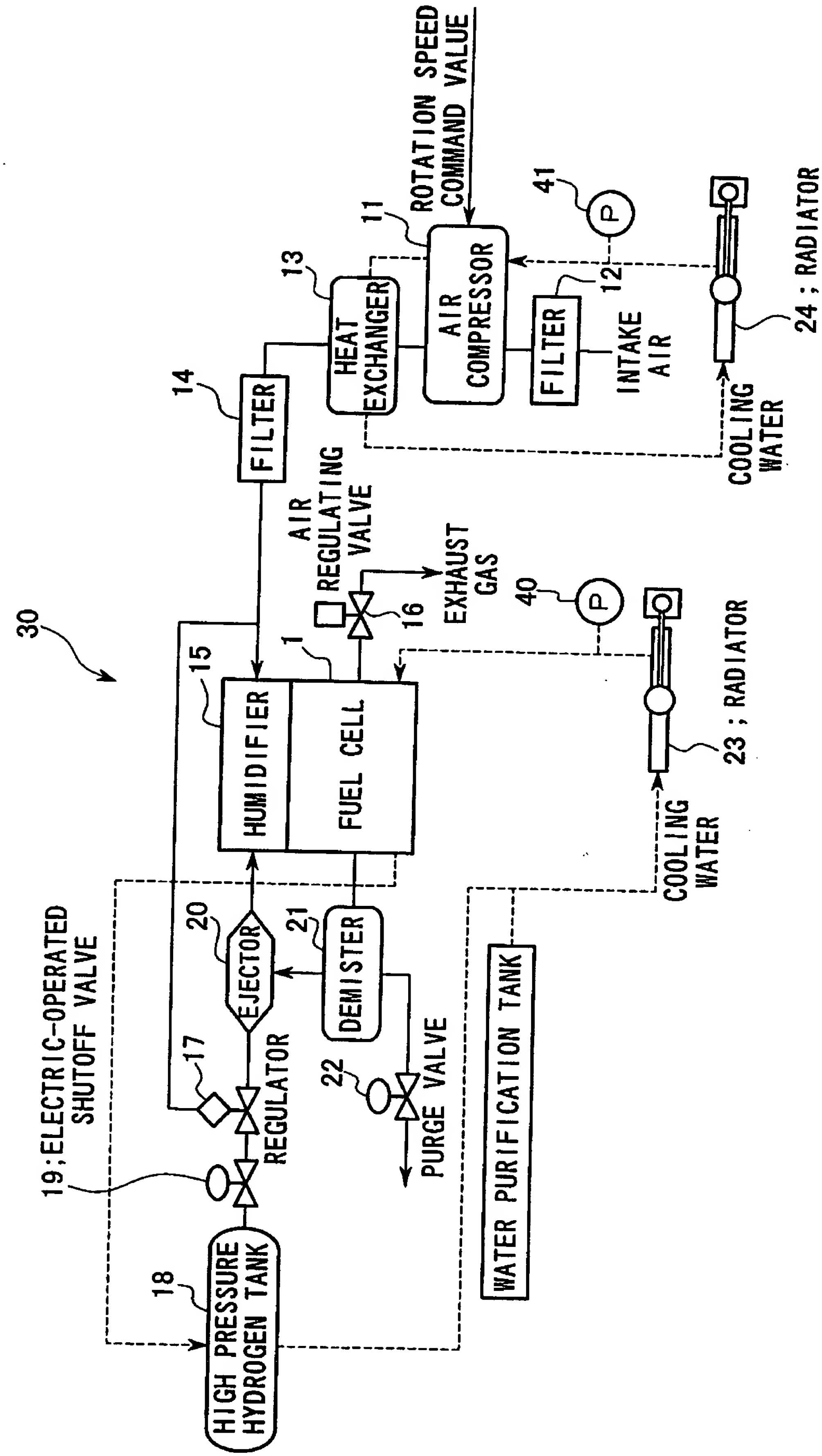
[Document Type] Drawing

[FIG. 5]



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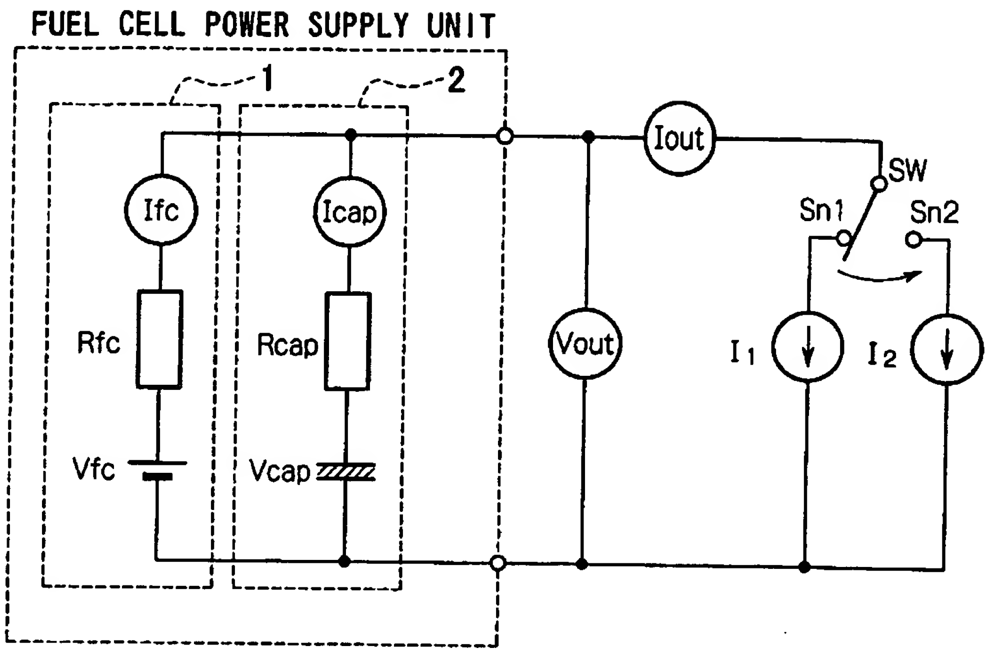
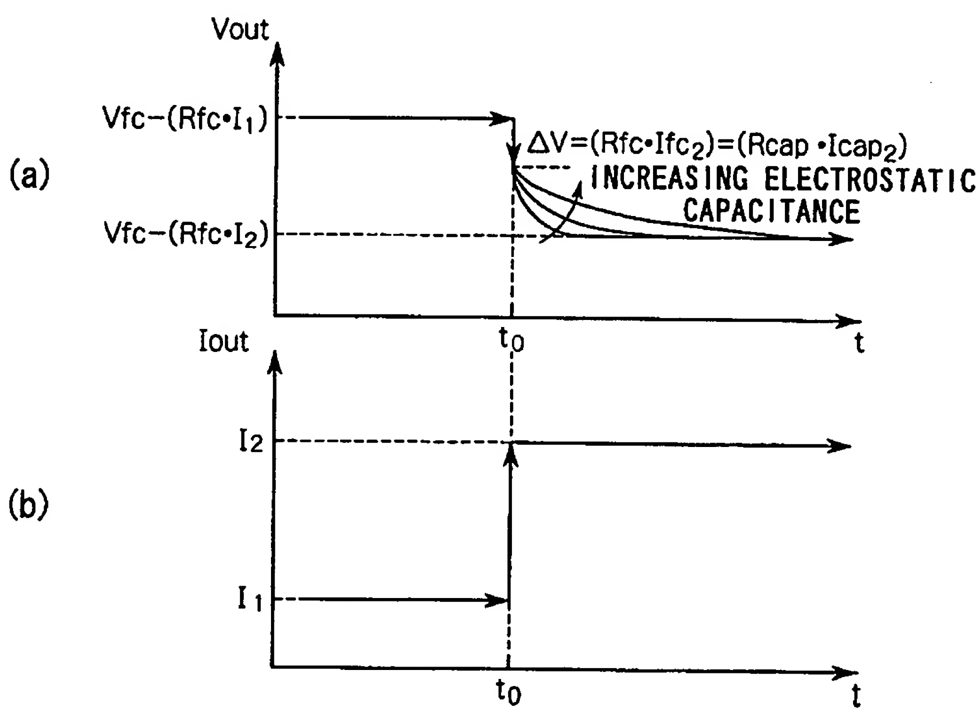
[Document Type] Drawing

[FIG. 6]

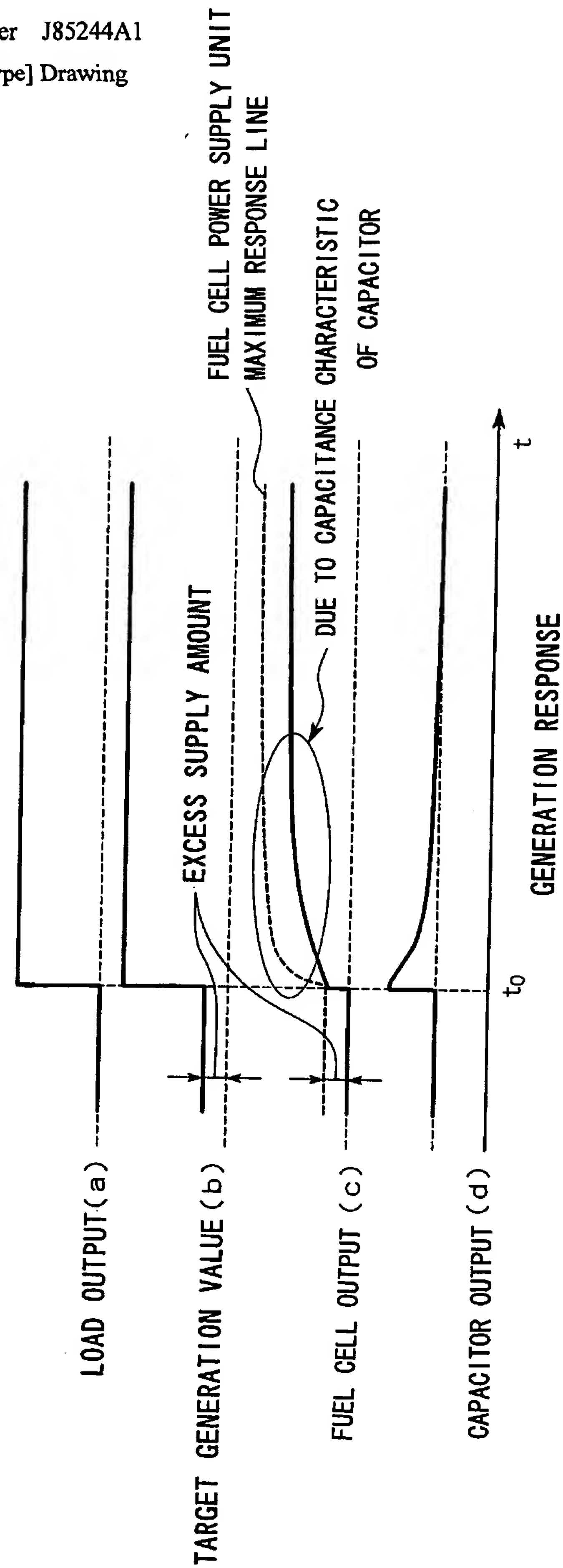


[FIG. 7]



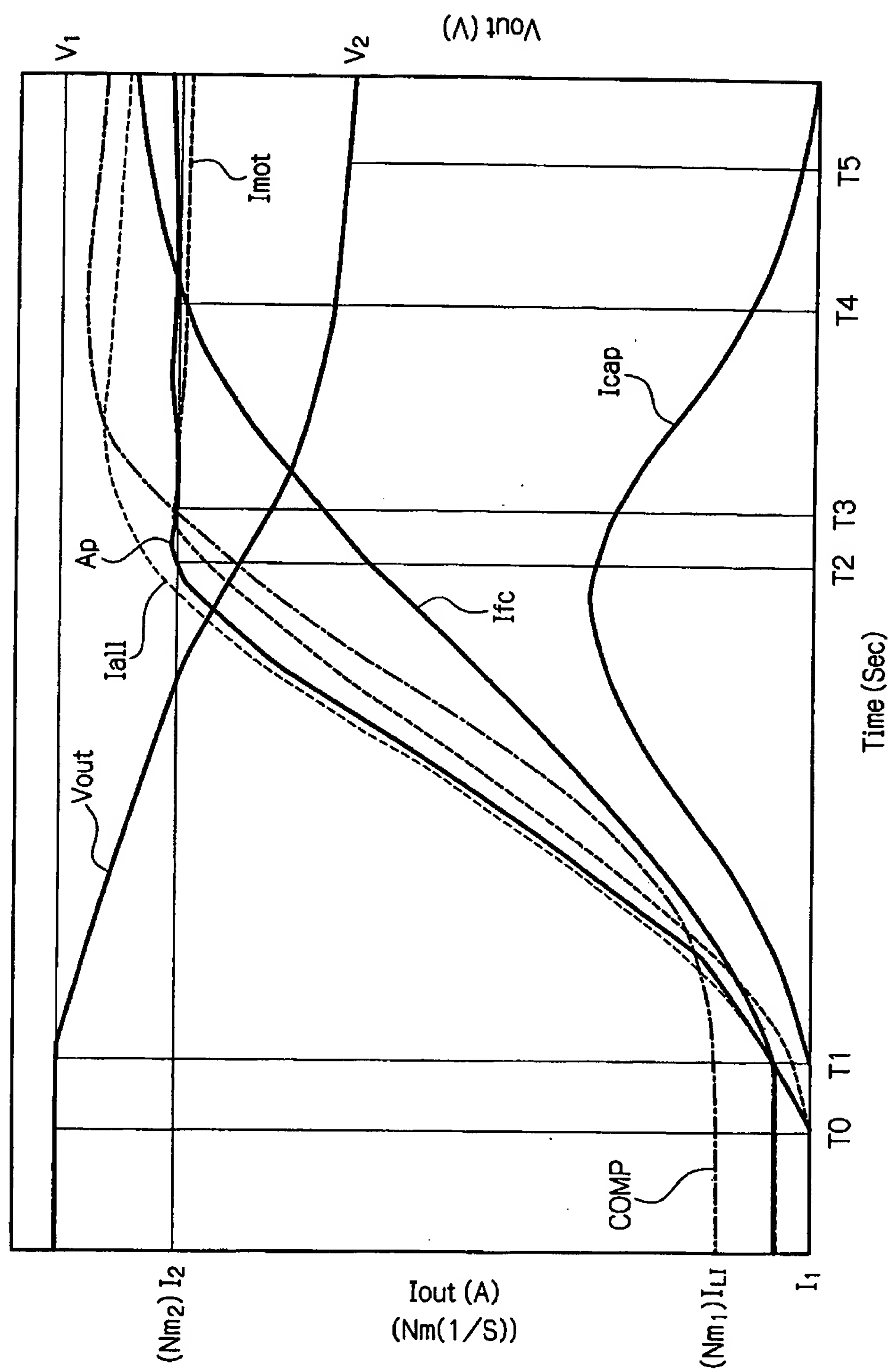
Docket Number J85244A1
[Document Type] Drawing

[FIG. 8]



Docket Number J85244A1
[Document Type] Drawing

[FIG. 9]



[Document Type] Abstract

[Abstract]

[Problem to be Solved by the Invention] To provide a fuel cell power supply unit that has a high power output efficiency by using a fuel cell and an electric double layer capacitor in a good electrical conducting state.

[Means for Solving the Problem] A fuel cell power supply unit of the present invention sets an excess supply amount with respect to the amount of the reacting gas supplied to the fuel cell in the output equilibrium state and a characteristic value of said electric double layer capacitor such that a synthetic output voltage V_{d1} of the fuel cell and the electric double layer capacitor immediately after the predetermined load current variation is given is higher than the voltage V_{LI1} corresponding to the output current I_{LI1} of the fuel cell that equilibrates with the amount of the reacting gas that has been supplied by the reacting gas supply system of the fuel cell before the load current is varied.

[Selected Drawing] FIG. 1